Available online at www.sciencedirect.com
ScienceDirect
Energy Procedia 86 (2016) 215 – 218
Energy Procedia

The 8th Trondheim Conference on CO_2 Capture, Transport and Storage

Environmental gains and impacts of a CCS technology – case study of post-combustion CO_2 separation by ammonia absorption

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Abstract

Considering the impacts of human activities on the environment, emissions of greenhouse gases are one of the major concerns. The CCS technologies are seen as an option that can help to decrease the emissions of CO_2 and reduce potential effects that a heightened CO_2 concentration might have. The technical solution of capture, transport and storage of the CO_2 originating in large emission point sources (power plants, industry) is depending on local conditions and can vary significantly. The ammonia scrubbing was chosen for CO_2 separation from flue gas of lignite coal power plant (typical conditions for the Czech Republic) in the national project MPO FR-TI1/379. Environmental gains and impacts of the power plant and the optimized variant of the capture technology based on ammonia scrubbing were assessed on the basis of material and energy flow balance. The potential environmental impacts of the power plant with and without CO_2 capture were compared using LCA methodology.

Peer-review under responsibility of the Programme Chair of the 8th Trondheim Conference on CO_2 Capture, Transport and Storage

Keywords: CO_2 capture; LCA; ammonia absorption

1. Introduction

Coal is one of the most important global energy sources. Despite being non-renewable coal is relatively evenly distributed around the world, it is providing electricity and heat with high reliability and the available known reserves are sufficient into far future. However, the energy production based on coal combustion is accompanied by

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Peer-review under responsibility of the Programme Chair of the 8th Trondheim Conference on CO_2 Capture, Transport and Storage
doi:10.1016/j.egypro.2016.01.022

significant environmental impacts – depletion of non-renewable resources and emissions of solid, liquid and gaseous compounds with potential negative impact on the environment and human health. The legislation is setting emission limits on sulfur dioxide, nitrogen oxides and particulates, which have environmental effects that can be observed in short term horizon as acid rain, photochemical smog and increased incidence of respiratory diseases. Reliable technological solutions are available to reduce the above mentions emissions – flue gas desuphurisation, denitrification and dedusting. The situation is much more complex in case of CO_2 emissions as the long term effects must be considered. It also proves to be very difficult to exactly quantify the effect of anthropogenic CO_2 on global warming.

Coal will most likely remain an important element of the global energy production even in long term future. It is necessary to find ways how to utilize coal more efficiently and with fewer emissions, including CO_2, in the future. As an illustration the Global CCS Institute specified long term CO_2 reduction measures: transfer to renewable energy sources, transfer to low carbon technologies and implementation of CCS (Carbon dioxide capture and sequestration) technologies on existing and newly planned facilities. [1]

The comparison of renewable energy sources and conventional thermal power plants with implemented CCS technology is often discussed. The study of Viebahn et al. [2] is using life cycle analysis (LCA) and cost analysis to compare the environmental impacts of pulverized combustion of hard coal, pulverized combustion of lignite, natural gas combustion in combined cycle and integrated gasification and combustion of hard coal – all option without and with CCS technology. These conventional energy sources are compared with renewables – wind and solar thermal systems. The authors point out that even with the best case of CCS technology the traditional sources still emit more CO_2 per 1 kWh of produced electricity than the renewables. However, thermal power plants are very significant source of energy (totaling e.g. about 52 % respectively 60 % of the energy mix in Czech Republic and Germany) and CCS technologies could help to mitigate its CO_2 emissions.

Many other studies were conducting LCA of parts of the whole CCS chain and also its parts comparing different types of energy applications with and without CCS. [1] The LCA is always applied on simulated power plants so the results can only function as estimation. Moreover, modern power plant blocks with high power output and net efficiency around 45 % are used. This paper is using LCA to assess the environmental impacts of an existing lignite fired PCC power plant block (net efficiency 32 %), see parameters in Table 1. The reference power plant environmental impacts are compared with the scenario of ammonia scrubbing CCS technology implementation.

Table 1: The parameters of the power plant block without and with CO_2 capture

Parameter	Power plant without CCS	Power plant with CCS
Nominal power output [MW]	250	250
Net power output [MW]	226	164
Yearly operation [h]	6 300	6 300
Electricity produced [MWh/y]	1 423 800	1 033 200
CO_2 produced [t/MWh]	0,933628	0,128049
CO_2 captured [t/MWh]	0	1,158537

2. The scenarios for LCA

The aim of this paper is to compare the environmental impacts of an existing power plant with the scenario of ammonia scrubbing CCS technology implementation. The used background data were taken from the national project MPO FR-TI1/379, for more information see the project report. [8] The above mentioned project’s aim was to suggest and design commercially available CCS technologies in the case their implementation on Czech existing power plants is needed in near future. The parameters of a power plant block in Table 1 are taken from a real facility and represent the existing conditions in the Czech Republic. The ammonia scrubbing was suggested as one of the options.

The LCA of environmental impacts is using the data related to the power plant and CO_2 capture operation. Impacts of CO_2 transportation and storage are not taken into account. Also the impacts of absorber construction and additional auxiliaries and infrastructure are disregarded due to its minimal importance compared to construction of the whole power plant.

The analysis was carried out using SIMAPro software and CML 2001 methodology. All inputs´ consumption and outputs´/wastes´ production were related to the production of 1 kWh of electrical energy. Three scenarios were included in the analysis and compared:

Scenario 1: The reference power plant without CO_2 capture

Scenario 2: Power plant with CO_2 capture based on ammonia scrubing

Scenario 3: Power plant with CO_2 capture and with utilizing the ammonia salts as fertilizer (previous variant treated ammonia salts as solid waste)

Table 2 is showing the selected environmental impacts expressed in equivalent units representative for each category.

Table 2: Environmental impacts

Category	Scenario 1: Power plant without CO_2 capture	Scenario 2 Power plant with CO_2 capture	Scenario 3 Power plant with CO_2 capture + fertilizer production
Mineral resources depletion [kg Sb eq.]	$6{,}67 . 10^{-9}$	$1{,}31 . 10^{-8}$	$1{,}23 . 10^{-8}$
Fossil fuels depletion [MJ]	1,22	4,29	4,24
Climate change [kg CO_2 eq.]	2,18	$5{,}25 . 10^{-1}$	$5{,}12 . 10^{-1}$
Ozone layer damage [kg R-11 eq.]	$8{,}38 . 10^{-12}$	$2{,}48 . 10^{-11}$	$2{,}45 . 10^{-11}$
Photochemical oxidation [kg C_2H_2 eq.]	0,00011	0,00012	0,00012
Acidification [kg SO_2 eq.]	0,0024	0,0022	0,0022
Eutropication [kg PO_4^{3-} eq.]	0,00032	0,00022	0,00021

3. Conclusions

The impact of CO_2 capture on climate change is expectedly positive and very significant. However, increased mineral resources and fossil fuel depletion can be observed for the power plant with CO_2 capture as well as increased ozone layer damage. The categories of photochemical oxidation and acidification seem unchanged, slight decrease of eutropication occurred with including the CO_2 capture. The option with CO_2 capture and ammomium salt utilization as fertilizers (Scenario 3) showed similar but slightly better results. [2, 3, 7]

The observed negative environmental impacts of the ammonia scrubbing are caused by two mechanisms. The process consumes a large amount of energy and decreases the net power output by a significant amount (see Table 1). Negative impacts of the power plant related to 1 kWh of electricity will thus increase. Second reason that increases the negative impacts is the simple fact of adding a new technology with additional demand of inputs and additional production of wastes to be treated..

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